

New IceCube data and color octet neutrino interpretation of the PeV energy events

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Abstract

IceCube collaboration has published two papers on ultrahigh energy neutrinos observation, recently. They have used the data collected in two years in their first publication, which reveals observation of two PeV energy neutrino events. The second publication of the collaboration including more data has also confirmed main features of the former paper. In literature, various interpretations of the IceCube data have been proposed. In this study, it is shown that PeV energy neutrino events observed by the IceCube collaboration can be interpreted as resonance production of color octet neutrinos with masses in 500 – 800 GeV range.

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1. INTRODUCTION

Observation of two PeV energy neutrino events by the IceCube collaboration [1] has led to plenty of papers on the possible interpretations of these events (see review [2] and references therein). As mentioned in Ref. [1]: “ The events were discovered in a search for ultrahigh energy neutrinos using data corresponding to 615.9 days effective live time and probability of observing two or more candidate events under the atmospheric background-only hypothesis is 2.9×10^{-3} (2.8σ)”.

Recent publication [3], which includes three years of IceCube data, has confirmed main features of previous two years data [4] (for discussion of IceCube data see Section 2): concerning PeV region one more events is observed, and there are no events between $0.4 PeV$ and $1 PeV$, as well as above $2.5 PeV$. These features may follow either from “ mono-energetic” neutrino source in PeV region or from TeV scale resonance in neutrino-nucleon scattering (or both). The gap in $0.4 \div 1.0 PeV$ region certainly means that excesses observed in $1 \div 2.5 PeV$ and $0.03 \div 0.4 PeV$ regions have different origins.

In Section 2 we present a brief summary of the IceCube results, emphasizing the gap between $0.4 PeV$ and $1 PeV$ as well as zero result for energies above $2.5 PeV$. Color octet neutrino (ν_8) phenomenology is considered in Section 3. Section 4 is devoted to ν_8 interpretation of PeV neutrino events. In Section 5 leptoquark interpretation of PeV events is reconsidered taking into account new IceCube data. Finally we give some concluding remarks in Section 6.

2. NEW ICECUBE DATA

As mentioned in previous section first two PeV events were observed by IceCube within 615.9 days effective live time. Results of two-year dataset [4], namely, 28 high-energy neutrino events within 662 days effective live time, are grouped in [2] as following (there is a misprint in the first item, $50 TeV$ should be replaced by $30 TeV$):

- 26 events from $50 TeV$ to $1 PeV$, which includes the ~ 10 atmospheric background events;
- 2 events from $1 PeV$ to $2 PeV$;
- zero events above $2 PeV$, say from $2 PeV$ to $10 PeV$, with a background of zero events.

In a similar manner, results of three-year dataset [3], corresponding to 988 days effective live time, can be grouped as:

- 33 events from 30 TeV to 0.4 PeV , which includes the ~ 10 atmospheric background events;
- zero events from 0.4 PeV to 1 PeV , with a background of 0.2 events;
- 3 events from 1 PeV to 2.5 PeV , with a background of 0.02 events;
- zero events above 2.5 PeV , say from 2.5 PeV to 10 PeV , with a background of zero events.

As mentioned in the Introduction, these features may be followed from:

- "mono-energetic" neutrino source(s) in PeV region (see [2] and references therein), i.e. blazars or gamma ray bursts (GRB's);
- or from TeV scale resonance in neutrino-nucleon scattering, namely, leptoquarks or leptogluons (first interpretation has been considered in [5] and second one in [6]);
- or both.

Let us repeat that the gap in $0.4 \div 1.0 PeV$ region certainly means that excesses observed in $1 \div 2.5 PeV$ and $0.03 \div 0.4 PeV$ regions have different origins.

All the three PeV energy events (event ID's 14, 20 and 35 in [3]) has shower type event topology. Two events observed in first two years have deposited energies $1041^{+132}_{-144} PeV$ and $1141^{+143}_{-133} PeV$. Third event observed during third year has deposited energy $2004^{+236}_{-262} PeV$.

3. PHENOMENOLOGY OF COLOR OCTET NEUTRINOS

Color octet (decuplet) neutrinos and leptons as well as color sextet ($15 - plet$) quarks are predicted by preonic models with colored preons [7–10]. There are two strong arguments favoring preon models: inflation of “fundamental” particles and free parameters in the SM (other BSM models, including SUSY, drastically increase the number of free parameters) and mixing of “fundamental” quarks and leptons. The first one, namely “inflation”, historically results in discovery of new level of matter two times during the last century: periodical table of chemical elements was clarified by Rutherford experiment, inflation of hadrons results in quark model (see Table 1 from [11]).

Recently, color octet leptons have been come to forefront again [12–16]. It should be noted that concerning preon models color octet neutrinos has the same status as color octet

leptons, and the status of both of them is similar to exited leptons and neutrinos, which are widely investigated by ATLAS and CMS collaborations [17–20].

Fermion-scalar and three-fermion models (see [10] and references therein):

Keeping a minimal scheme in mind, we make two assumptions: i) There is no paras-tatistics, ii) Preons are colored objects. According to the first assumption the SM fermions should contain odd number of fermionic preons, which lead to fermion-scalar models or three fermion models. The second assumption means that preons are color triplets.

Leptons: In the framework of fermion-scalar models, leptons would be a bound state of one fermionic preon and one scalar anti-preon

$$l = (F\bar{S}) = 1 \oplus 8$$

then each SM lepton has one colour octet partner. In a three fermion model, the color decomposition

$$l = (FFF) = 1 \oplus 8 \oplus 8 \oplus 10$$

predicts the existence of two color octet and one color decouplet partners.

Quarks: In fermion-scalar models, anti-quarks are consist of one fermionic and one scalar preons which means that each SM anti-quark has one colored sextet partner

$$\bar{q} = (FS) = \bar{3} \oplus 6$$

According to the three fermion models

$$q = (F\bar{F}F) = 3 \oplus \bar{3} \oplus \bar{6} \oplus 15$$

therefore, for each SM quark one anti-triplet, one anti-sextet and one 15-plet partners are predicted.

In this paper we consider color octet neutrinos in the framework of fermion-scalar models. The interaction lagrangian for color octet neutrinos is given by

$$L = \frac{1}{2\Lambda} \sum_l \{ \bar{\nu}_{l8}^a g_s G_{\mu\nu}^a \sigma^{\mu\nu} (\eta_L \nu_{lL} + \eta_R \nu_{lR}) + h.c. \}. \quad (1)$$

Here, Λ is compositeness scale, $G_{\mu\nu}^a$ is field strength tensor for gluon, index $a = 1, 2, \dots, 8$ denotes the color, g_s is the gauge coupling, η_L and η_R are the chirality factors, ν_{lL} and ν_{lR} denote left and right spinor components of neutrino ($l = e, \mu, \tau$), $\sigma^{\mu\nu}$ is the antisymmetric tensor. According to neutrino chirality conservation, $\eta_L \eta_R = 0$. We set $\eta_R = 0$ in this analysis.

According to PDG [21] current exclusion limit for color octet neutrino is $M_{\nu_8} > 110 \text{ GeV}$ assuming $\nu_8 \rightarrow \nu + g$ decay. This value is obtained from Tevatron data, a rough estimation shows that M_{ν_8} below 400 GeV could be excluded by current LHC data.

4. COLOR OCTET NEUTRINO AS THE SOURCE OF ICECUBE PEV EVENTS

Feynman diagram for resonant ν_8 production in νN scattering is given in Figure 1.

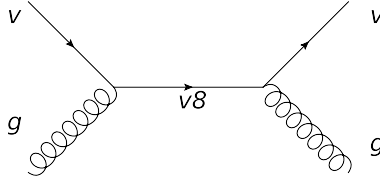


Figure 1. Resonant ν_8 production in the ultra high energy neutrino nucleon scattering.

In order to perform numerical calculations we implement color octet neutrino interaction lagrangian, given in Eq. 1, into the CalcHEP software [22]. In Fig. 2 we present ν_8 production cross-section as a function of incoming cosmic neutrino energy for different ν_8 mass values. For numerical calculations we set $\Lambda = m_{\nu_8}$ together with *CTEQ6L* [23] parton distributions. It should be noted that resonance cross-section is proportional to $(\eta_L/\Lambda)^2$.

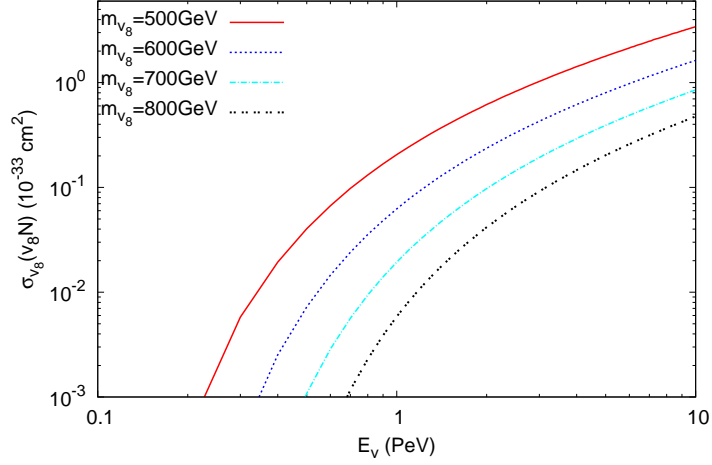


Figure 2. ν_8 production cross section in νN scattering.

In order to obtain ν_8 production rate distribution the cross-section given in Fig. 2 should be convoluted with ultra high energy neutrino flux. According to [3] the best fit power law for extraterrestrial neutrino flux is

$$E^2 \phi(E) = 1.5 \times 10^{-8} (E/100 \text{ TeV})^{-0.3} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \quad (2)$$

for each neutrino species. For the calculation of production rate distribution we use

$$dN_{\nu_8}/dE_\nu = nt\Omega\sigma_{\nu_8}\phi(E) \quad (3)$$

where $t = 988$ days is the time exposure, $n = 6 \times 10^{38}$ is the effective number of target nucleons in IceCube and $\Omega = 4\pi$.

In ν_8 interpretation, there are three possible sources of PeV events namely ν_{e8} , $\nu_{\mu 8}$ and $\nu_{\tau 8}$. Real picture depends on ν_8 mass hierarchy. Below we assume that masses of color octet neutrinos are close to each other. Production rate distribution dN_{ν_8}/dE_ν is given in Fig. 3.

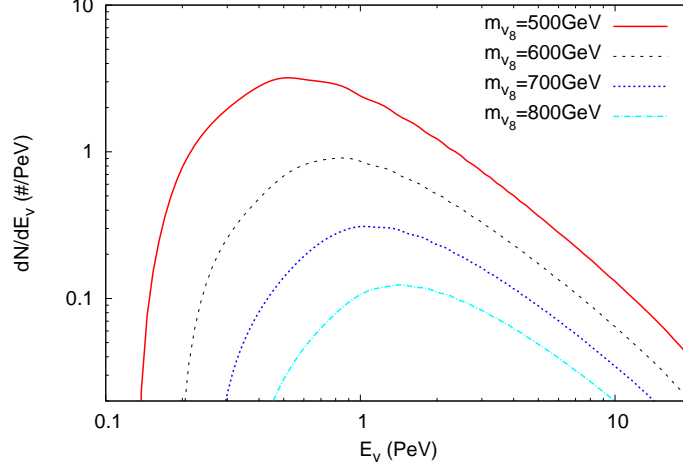


Figure 3. Production rate distribution dN_{ν_8}/dE_ν from the ν_8 cross-section convoluted with extraterrestrial neutrino flux.

Up to this stage, procedure is similar to leptoquark case that considered in [5] and rough estimations for ν_8 case performed in [6]. Concerning ν_8 interpretation, in fact essential part of energy is carried by neutrino, therefore it is invisible, and IceCube shower is formed by gluon. For this reason gluon rate distribution, presented in Fig. 4, is more appropriate for IceCube data analysis.

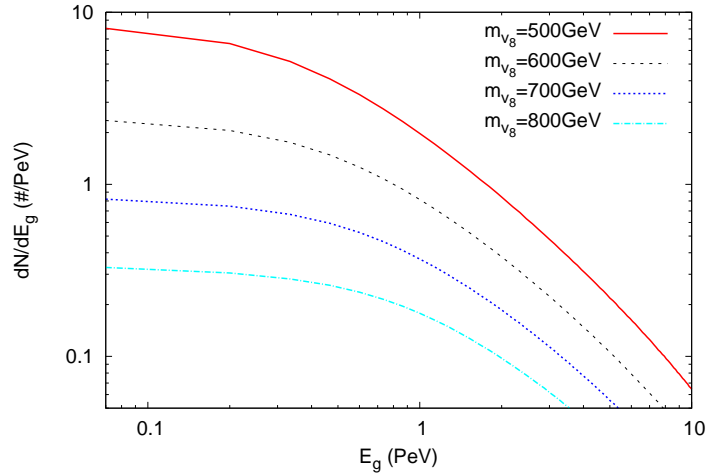


Figure 4. Event rate distribution dN_{ν_8}/dE_g from the gluon energy distribution convoluted with extraterrestrial neutrino flux.

Let us turn to interpretation of IceCube PeV energy events. As mentioned in Section 2,

there are 3 events in $1 - 2.5 \text{ PeV}$ region, whereas there are no events in $0.4 - 1 \text{ PeV}$ region and above 2.5 PeV . In our analysis, we use 3 observed events as a basic point. Then referring to Fig. 2 from [3], we use 2.5 (3.5) events as upper limit for $0.4 - 1$ ($2.5 - 10$) PeV regions. In Table 1 we present expected number of events in different energy regions normalized to 3 events observed in $1 - 2.5 \text{ PeV}$ region. Last column contains values of η_L which provides exactly 3 events in $1 - 2.5 \text{ PeV}$ region.

Table I. Number of events for different masses of color octet neutrinos

m_{ν_8}, GeV	$0 - 0.4 \text{ PeV}$	$0.4 - 1.0 \text{ PeV}$	$1.0 - 2.5 \text{ PeV}$	$2.5 - 10 \text{ PeV}$	η_L
500	4.8	2.3	3.0	2.4	0.4
600	3.4	2.2	3.0	2.7	0.6
700	2.4	2.0	3.0	3.0	0.9
800	1.9	1.9	3.0	3.3	1.2

It is seen that color octet neutrinos with mass values between 500 and 800 GeV provide correct interpretation of IceCube data, whereas masses above 800 GeV lead to excess of events above 2.5 PeV . Mass value corresponding to $\eta_L = 1$ is approximately 740 GeV .

5. COMMENTS ON LEPTOQUARK INTERPRETATIONS OF PeV EVENTS

Leptoquark interpretation of two PeV events observed within first 2 years IceCube data [1] was proposed in [5]. As the result, authors mention that scalar leptoquark of charge $-1/3$, which couples to the first generation quarks and the third generation leptons, with a mass around 600 GeV and coupling $f_L = 1$ provides correct description of the data. In this section we reconsider their results using new (3 years) IceCube data. Using Fig. 3 from [5] we estimate number of events for different mass values and energy regions. Similar to Table 1 we use 3 observed PeV energy events as a basic point. Results are presented in Table 2.

Table II. Number of events for different masses of leptoquarks

$m_{\nu_{LQ}}, GeV$	$0 - 0.4 PeV$	$0.4 - 1.0 PeV$	$1.0 - 2.5 PeV$	$2.5 - 10 PeV$	f_L
500	2.5	6.4	3.0	1.2	1.0
600	0.5	3.9	3.0	1.1	1.3
700	0	2.1	3.0	1.0	1.7
800	0	1.1	3.0	0.9	2.2

It is seen that leptoquark interpretation is in conflict with new IceCube data if $m_{\nu_{LQ}}$ is below $650 GeV$, because it leads to excess of events in $0.4 - 1 PeV$ energy region. Leptoquark with mass above $650 GeV$ is in agreement with data, however coupling constant f_L should be larger than 1.5.

6. CONCLUSION

Observation of PeV energy neutrino events in the IceCube experiment may lead to serious consequences both for astrophysics and particle physics. In the light of our calculations, color octet neutrinos with masses in $500 - 800 GeV$ range give rational interpretation of the IceCube results on PeV energy neutrinos. In addition, scalar leptoquark with mass $650 - 700 GeV$ also provide reasonable mechanisms for IceCube data. Correctness of both interpretations may be checked in near future using forthcoming IceCube and LHC data.

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